

DIURNAL DENSITY VARIATIONS NEAR THE MESOPAUSE

J. W. Peterson and K. D. McWatters

Department of Aerospace Engineering

University of Michigan
Ann Arbor, Michigan

JUL 27 1967
AUG 1 1967
AUG 14 1967
AUG 21 1967
AUG 28 1967
SEP 4 1967
SEP 11 1967
SEP 18 1967
SEP 25 1967
OCT 2 1967

Presented at the Forty-Eighth Annual Meeting

American Geophysical Union

April 20, 1967

FACILITY FORM 602	N67-31121	
	(ACCESSION NUMBER)	(THRU)
	15	1
	(PAGES)	(CODE)
	CR-85866	13
	(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

Introduction

Diurnal variations of atmospheric density are a reasonable expectation due to the important effects of solar radiation. Density variations at high altitude have been derived by analyzing perturbations of satellite orbits. This technique is applicable between 700 Km, where the variation relative to average density is large, and 200 Km where the variation is small. At low altitude the technique is not applicable due to rapid decay of the orbit.

Near mesopause, between 85 and 105 Km, the radio-echo meteor technique indicates a considerable variation of density ratio. Maximum density occurs later in the afternoon than at higher altitude.

The falling sphere data presented here is also applicable near mesopause. Sphere data was found to be in qualitative agreement with the radio-echo meteor data. Irregular density profiles indicate that important effects other than diurnal are present.

Satellite acceleration measurements

Atmospheric density has been obtained by Jacchia (1960) and others by analysis of satellite accelerations caused by drag. An eccentric orbit is desirable in this application because significant drag effects occur only near perigee. Several orbits are required to obtain a perturbation of practical size. The coordinates of the perigee point relative to the earth-sun line tend to translate at a slow rate due to the earth's motion about the sun. The effects of the earth's oblateness on the elements of the satellite orbit also causes a movement of the perigee point. Data may therefore be obtained over a period of many days as the perigee point slowly traces its path through the diurnal bulge. An empirical model for the density of the upper atmosphere between

200 and 700 Km has been obtained in this way, Figure 1. The important characteristics of this model are a symmetrical density distribution with a maximum at the latitude of the subsolar point and longitude lagging two hours behind the subsolar point. The relative diurnal density increase is largest at 700 Km and smallest at 200 Km. Below 200 Km the model is undefined due to the short lifetime of satellites at this altitude which reduces the amount of available data. The diurnal effect is explained by extreme-ultraviolet heating between 100 and 200 Km and by corpuscular heating. Recently it has been reported that a more accurate model of the bulge should be elongated north and south rather than symmetrical and should place the density maximum over the equator rather than over the latitude of the subsolar point. (Jacchia and Slowey 1966). These effects may be due to meridional atmospheric motion. In any case the model is necessarily an idealized one since it represents average conditions over a period of days rather than a single day.

Radio-Echo Meteor Measurements

Meteors burn away between heights of about 80 to 110 Km leaving ionized trails which can be detected by radio equipment. Two separate methods were used by Greenhow and Hall (1960), at Jodrell Bank Experimental Station (53° N., 2° W.). The first method depends upon the measurement of the ambipolar diffusion coefficient which is a function of the atmospheric density and temperature.

$$D = k \sqrt{T}/\rho$$

The second method is to measure the heights of occurrence of meteors with different velocities. Theories of meteor evaporation indicate that, for meteors of a given velocity, maximum ionization depends upon atmospheric density and temperature.

$$f(v) = \rho T^{2/3}$$

Similar results were obtained from the two methods which lends credence to the meteor data. The error of each height determination is about 4 Km. It was therefore desirable to use a large number of meteor echoes in order to improve the accuracy of the measurement. Approximately 3000 meteor echoes could be obtained in ten days. These were analyzed according to time of day and are plotted in Figure 2. The peak to-peak variation is approximately 30 per cent which is much smaller than the diurnal variation at 700 Km but larger than at 200 Km according to satellite drag data. The maximum density occurs 3 to 6 hours after noon compared with a lag of 2 hours at high altitude. These differences should not be surprising since the diurnal variations near mesopause must have a source other than EUV heating which occurs at higher altitude. These results are also rather idealized in that they represent average results over a period of days rather than a single day. The density maximum occurs about 3 hours after noon in the 1958 data and about 6 hours after noon in the 1959 data. There appears to be no obvious explanation for this difference.

Falling Sphere Data

These data were obtained from inflatable spheres deployed from Nike-Cajun sounding rockets at Wallops Station (38° N., 75° W.) and at Kwajalein (9° N., 168° E.). Figure 3 depicts a typical trajectory. The 66 cm spheres of mass 50 grams were tracked by radar to obtain data on both ascent and descent portions of the trajectory. The radar data were analyzed to obtain velocity and acceleration. Atmospheric density was obtained using the drag equation.

$$D = \frac{1}{2} C_D A \rho V^2$$

Further details were reported by Peterson et al., (1965). Figure 4 shows density, temperature, and wind data from a typical sounding. Eight soundings

were suitable for studies of the diurnal variation, Table 1. Various day-night and night-night pairs were selected and density change was plotted, Figure 5. The first sounding of each day-night pair occurred at $1\frac{1}{2}$ hours after local noon, and the second in darkness, either early or late evening. The first four profiles appear to have no clear cut trend in common which suggests that the diurnal change is not the dominating effect. Apparently there are other heating effects of equal importance that do not repeat on a diurnal cycle. The fifth and last profile of Figure 5 depicts density change at the same early evening hour between 2 soundings 10 days apart. This profile shows density change as large as any of the day-night pairs which indicates that important heating effects other than diurnal are present. The average density change of 4 day-night pairs is compared with the Greenhow and Hall data, Figure 6.

Discussion

The average diurnal density change as measured by falling spheres is at most half the change measured by the meteor technique, Figure 6. A possible explanation is that the rockets were not launched at the time of maximum and minimum density. Two or three soundings are obviously not sufficient to define the time of maximum or minimum density. The 1958 meteor data indicates nearly maximum density at $1\frac{1}{2}$ hours after local noon but the 1959 meteor data indicates average density at this time. It appears likely that a larger density change would have been found if maximum and minimum density had been selected from a larger group of soundings in the 24 hour period.

Density changes in the atmosphere can be explained by heating at lower levels which causes an expansion and an elevation of relatively dense air to a higher altitude. High altitude density changes are believed to be due

to euv heating between 100 and 200 Km (Jacchia and Slowey, 1966). Heating at a lower altitude must be postulated to explain density changes near mesopause. Webb(1966) has assumed heating in the ozonosphere that amounts to a diurnal change of 10° K between 40 and 60 Km, sufficient to elevate the atmosphere .75 Km. An elevation of about 1.5 Km would be required to explain the 30 per cent density change reported by Greenhorn and Hall.

According to Hines (1965) wave motion in the atmosphere is capable of depositing significant amounts of energy at mesopause or higher altitude. A possible explanation for irregular density fluctuations might come from gravity waves which are guided by irregular forces.

Another possible explanation for irregular behavior of density fluctuations may be energy released by recombination of atomic oxygen which has descended from higher levels. Kellogg (1961) has explained warmings of the polar mesosphere in this way and his theory might be applicable to the present problems.

TABLE 1

Time of Launch

Rocket Number	Hour-LMT (Solar)	Date	Sunrise	Sunset	Place
PMR 15	1329	18 Jun 1964	0541	1821	Kwajalein
PMR 16	0340	19 Jun 1964			
NASA 10. 154 UA	1330	7 Aug 1965	0508	1902	Wallops
NASA 10. 169 UA	2240	7 Aug 1965			
NASA 10. 157 GM	0340	8 Aug 1965			
NASA 10. 158 UA	2052	24 Jan 1966	0711	1713	
NASA 10. 159 UA	1331	3 Feb 1966	0703	1717	
NASA 10. 143 UA	2054	3 Feb 1966			

References

- Greenhow, J. S., and J. E. Hall, Diurnal variations of density and scale height in the upper atmosphere, J. Atmospheric Terrest. Phys., 18, 203-214, 1960.
- Hines, C. O., Dynamical heating of the upper atmosphere, J. Geophys. Res., 70, 177-183, 1965.
- Jacchia, L. G., A variable atmospheric-density model from satellite accelerations, J. Geophys. Res., 65, 2775-2782, 1960.
- Jacchia, L. G., and J. Slowey, The shape and location of the diurnal bulge in the upper atmosphere, Space Research VII, Vol. 2, 1077-1090, North-Holland Publishing Co., Amsterdam, 1966.
- Kellogg, W. W., Warming of the polar mesosphere and lower ionosphere in the winter, J. Meteorol., 18, 373-381, 1961.
- Peterson, J. W., W. H. Hansen, K. D. McWatters, and G. Bonfanti, Falling sphere measurements over Kwajalein, J. Geophys. Res., 70, 4477-4489, 1965.
- Webb, W. L., Stratospheric tidal circulations, Space Research VII, Vol. 1, 363-375, North-Holland Publishing Co., Amsterdam, 1966.

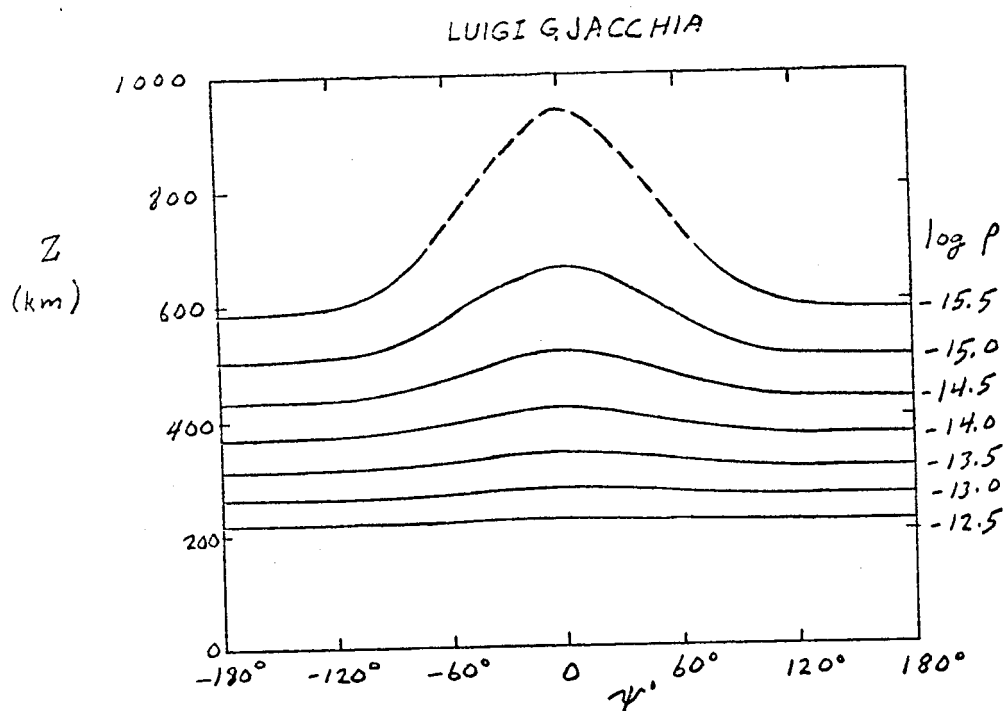


Fig. 1 Heights of surfaces of equal density above a great circle across the diurnal bulge.

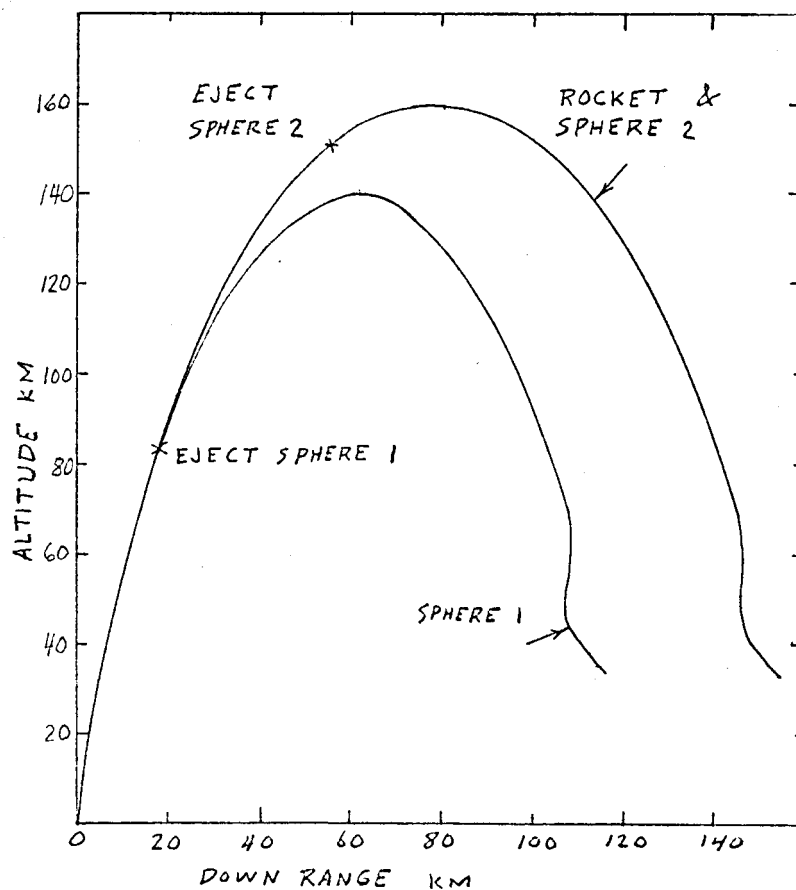
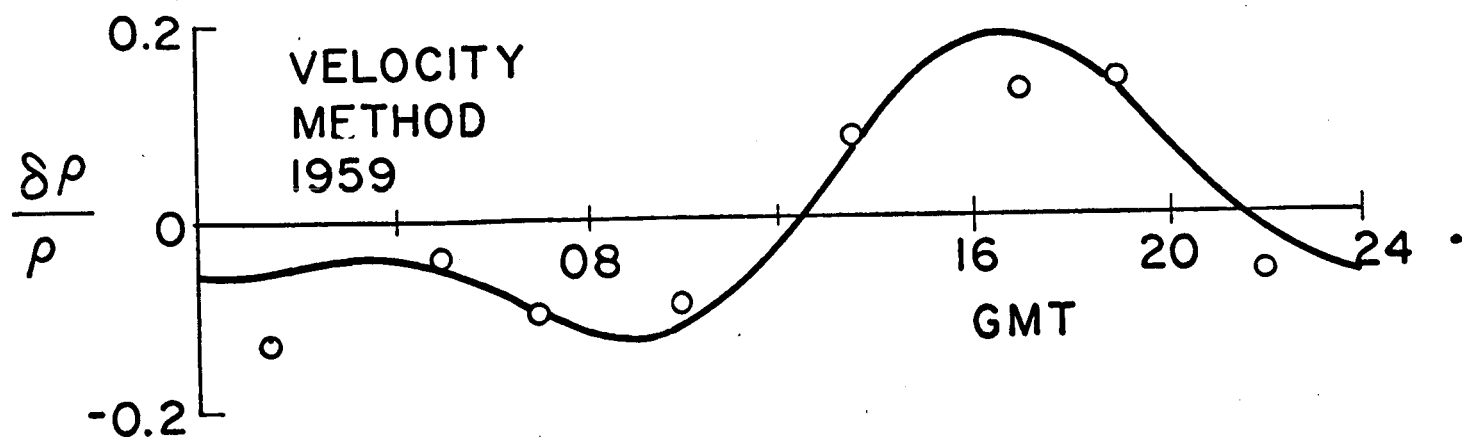
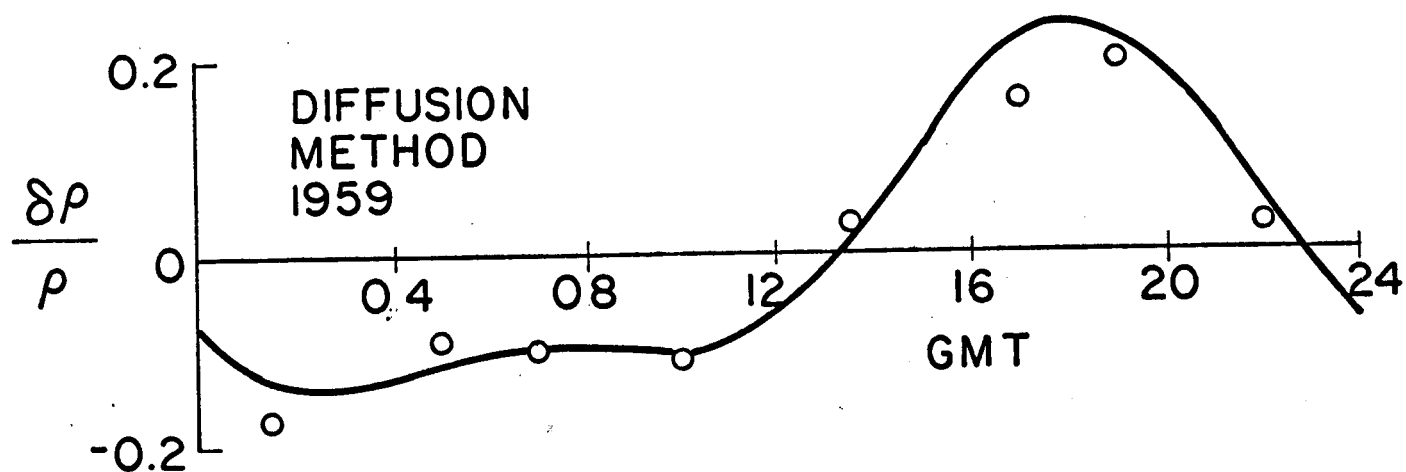
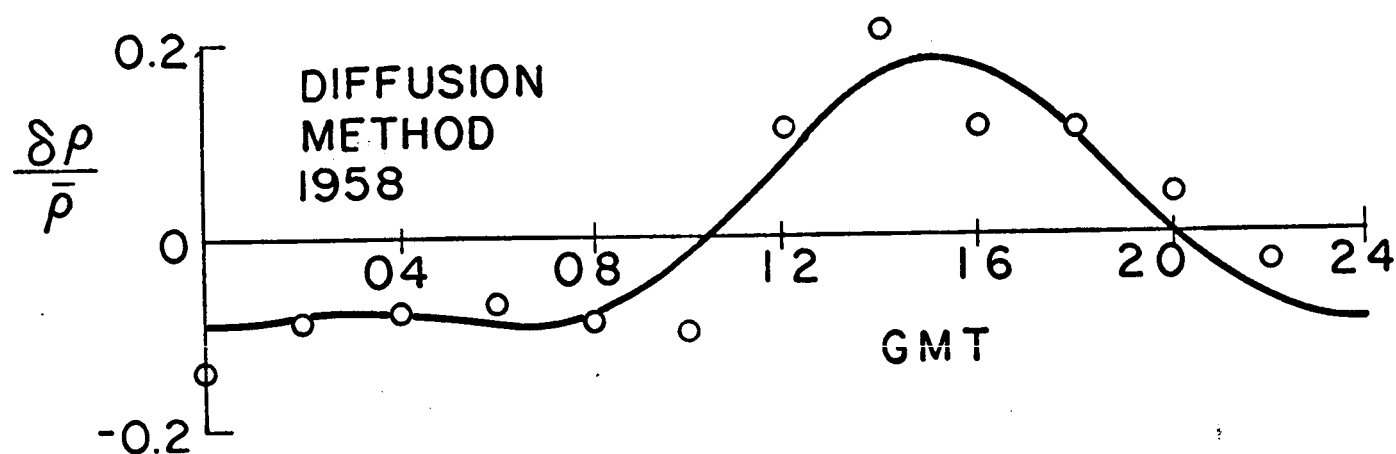


Fig. 3 Typical Trajectory. Rocket launched at Wallops Station.

GREENHOW AND HALL METEOR DATA
 DIURNAL DENSITY VARIATION AT 96 KM
 JAN - FEB 1958 AND 1959 ~3000 METEORS



DIURNAL DENSITY VARIATIONS
UNIVERSITY OF MICHIGAN
FALLING SPHERE SOUNDINGS
AVERAGE OF FOUR PAIRS

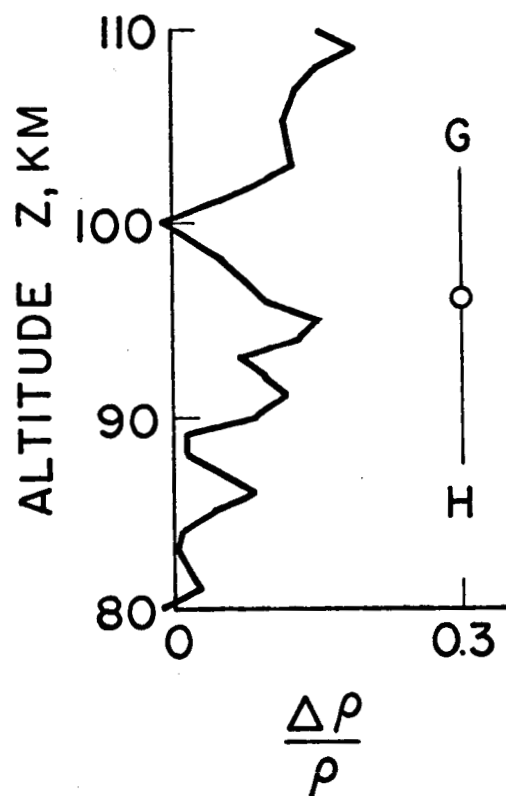
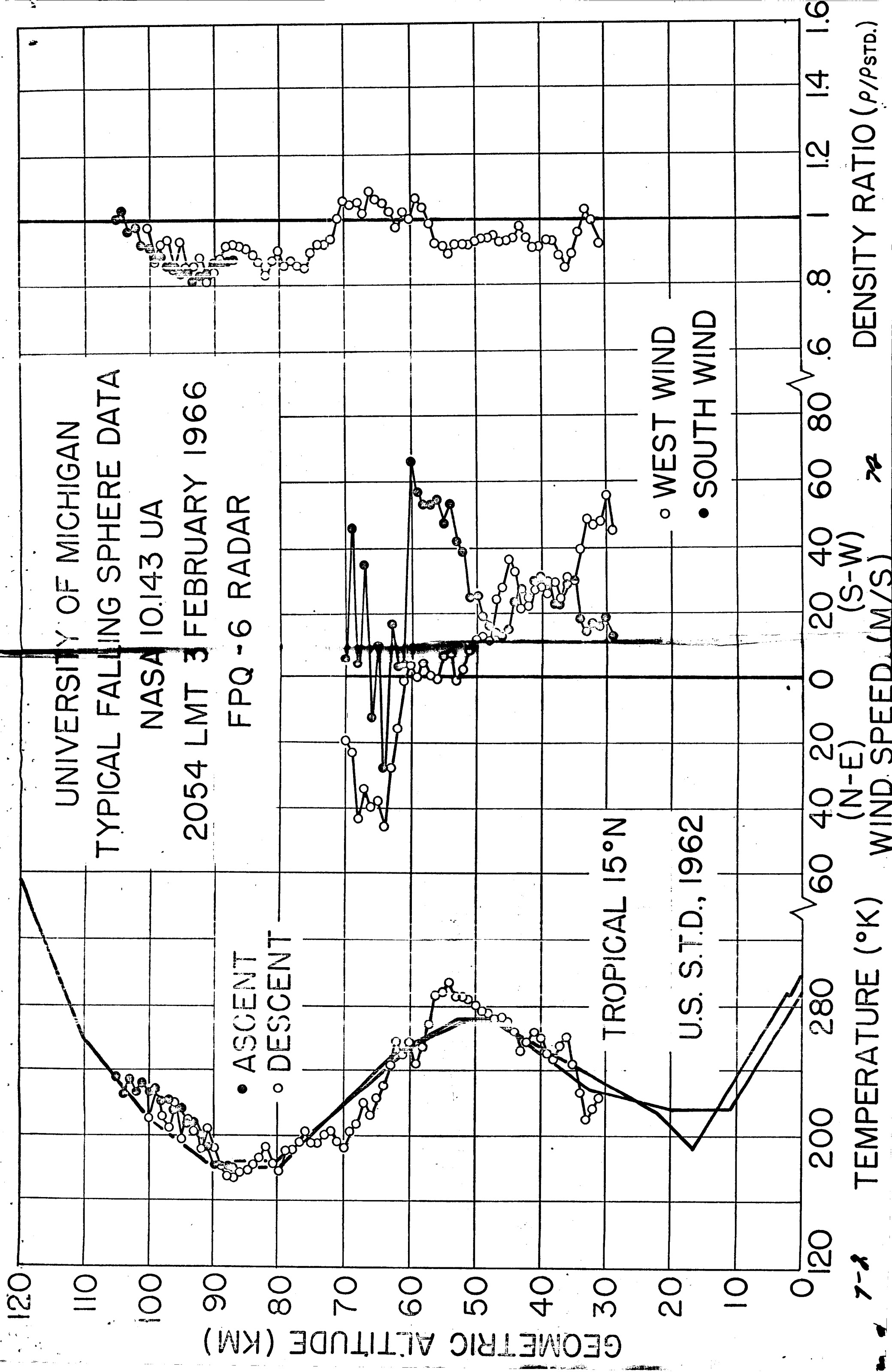
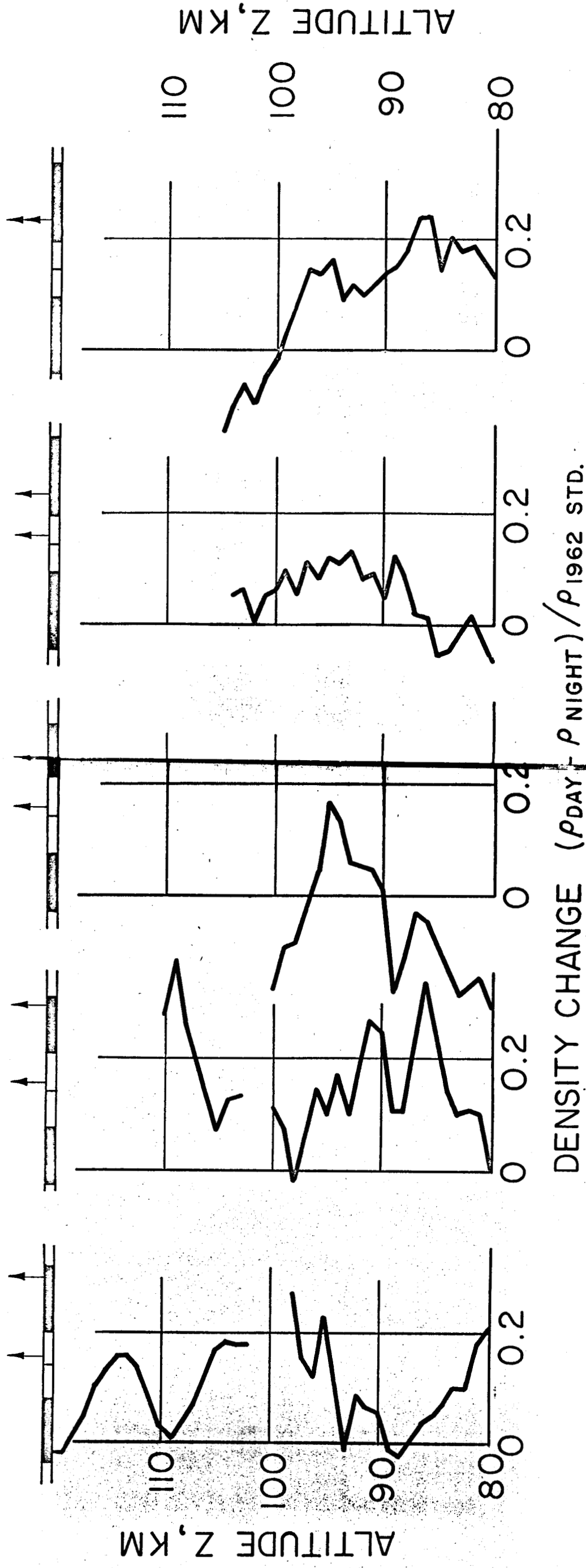


Fig. 6



DIURNAL DENSITY CHANGE INDICATED BY PAIRS OF FALLING SPHERE SOUNDINGS UNIVERSITY OF MICHIGAN



KWAJALEIN 1964
1329 LMT 18 JUNE
0340 LMT 19 JUNE

WALLOPS ISLAND 1965
1330 LMT 7 AUGUST
0340 LMT 8 AUGUST

WALLOPS ISLAND 1965
1330 LMT 7 AUGUST
2240 LMT 7 AUGUST

WALLOPS ISLAND 1966
1331 LMT 3 FEBRUARY
2054 LMT 3 FEBRUARY

WALLOPS ISLAND 1966
2052 LMT 24 JANUARY
2054 LMT 3 FEBRUARY